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EXECUTIVE SUMMARY

WELDING UNIT - METALLURGICAL RESEARCH DEPARTMENT
REVIEW OF 1984 WORK PROGRAM AND PROPOSED WORK FOR 1985

M.J. Tinkler

This report reviews the activities of the Metallurgical Research Department's Welding Unit during 1984. Major research programs during the year included nuclear waste container welding, pulsed-current gas-metal-arc welding procedure development, welding automation and robotics, and repair welding technology, particularly temper-bead. Smaller research projects, and the substantial amount of field support and service work performed in 1984, are also summarized. Reports issued by the Welding Unit, as well as externally published papers and presentations are listed. Finally, the proposed activities and objectives for the Unit's 1985 work program are outlined, with particular reference to the major research areas carrying on from 1984.

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job	file	date	report no.
740681-801-081	823.1	March 18, 1985	85-37-K

Mr. F.J. Kee
Director of Research



ontario hydro
research division

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REVIEW OF 1984 WORK PROGRAM AND PROPOSED WORK FOR 1985

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This report reviews the activities of the Welding Unit of the Metallurgical Research Department during 1984. Reports issued by the Welding Unit, as well as externally published papers and presentations are listed. The direction of the Unit's major work programs for 1985 is also outlined.

1.0 INTRODUCTION

During 1984, the Welding Unit continued to pursue the two major objectives which have been at the heart of its work program for several years:

- to undertake welding research which will be of value to Ontario Hydro both in the short and long term;
- to provide laboratory services and engineering expertise to the Corporation's welding community in support of day-to-day activities in plant operations, maintenance and construction.

Major research activities for 1984 were in the following areas:

- nuclear fuel waste disposal container welding;
- pulsed current gas-metal-arc welding development;
- welding automation and robotics;
- repair welding technology, specifically temper-bead.

These work programs are reviewed in detail below, along with a number of smaller research projects also undertaken during the year. The substantial amount of field support and service work performed in 1984 is also summarized.

2.0 UNIT PERSONNEL AND WORK PROGRAM

In previous years, service work associated with weld procedure qualification

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and suppliers' weld quality evaluation comprised a major component of the Welding Unit's work program mix. Prior to the retirement of Mr. M.P. Lamey in 1983, this work area provided close to 100% transfer funding for two people in the Unit. With Mr. Lamey's retirement, the responsibility and considerable work load associated with this activity had to be transferred to the Unit's other engineers, with technical support provided by Metallurgical Services personnel. During the last quarter of 1983 and the first part of 1984, this created considerable strain on the Unit's ability to pursue its research programs effectively and efficiently.

Therefore, an important management objective for the Welding Unit in 1984 was to regain a work program balance which allowed research activities to be maintained at an appropriate level. With increasing experience, Unit engineers were able to deal with the service work load more efficiently. At the same time, excellent cooperation was gained from the Metallurgical Services Unit, particularly in their willingness to take responsibility for supplier weld quality evaluation work with Welding Unit personnel involvement limited to a consultative role. As a result, it was felt that a satisfactory level of research was maintained throughout the year. It should be added that this adjustment in the work program balance towards an increasing research and development fraction was met with considerable support from Ontario Hydro's welding community, in the form of sufficient transfer funding for R&D work to maintain a high transfer funding/OM&A ratio despite the reduced service work load.

Another factor contributing to the Welding Unit's productivity in 1984 was its relatively stable staffing situation. Compared to 1983, in which three staff members were lost and two new people hired, Unit personnel remained unchanged throughout 1984. Mr. M.J. Tinkler was appointed Acting Supervising Engineer - Metallurgy Section for a four-month period during the year, but this resulted in minimal disruption to the Welding Unit's work program and contributed to improved collaboration with Metallurgical Services staff.

At year's end, Welding Unit personnel were organized in the following manner to deal with the Unit's work programs:

Unit Head	M.J. Tinkler
Nuclear Waste	P.Y.Y. Maak
Container Welding	J.G. Galloway
Pulsed-GMA and	J.W. Prince
Repair Welding	R.W. Hopkins
Technology	
Automation & Robotics	S.C. McNabb
	K. Yiu
	P.Y.Y. Maak

Construction & Field
Support

P.Y.Y. Maak, J.W. Prince,
and Metallurgical Services staff.

In addition, all Unit staff periodically became involved in short term R&D programs and in a variety of small jobs and consultation work.

3.0 REVIEW OF 1984 WORK PROGRAM

3.1 Nuclear Fuel Waste Disposal Container Welding

This program is part of Ontario Hydro's technical assistance program to AECL and is directed towards defining the welding procedures for fabrication and closure of nuclear fuel waste disposal containers.

i) Titanium: Phase Three of the resistance/diffusion bonding program has been completed. Titanium ring mockups (~305 mm diameter and 6.4 mm thick) were bonded over a wide range of bonding parameters. Bonding procedural "tolerance boxes" for various bonding parameters have been defined for the specific bonding procedure which is being recommended for use in the final closure of the prototype titanium structurally supported container. In comparison to previous testing of 3.6 mm thick titanium strips, higher heat input was required to ensure sound bonding in these thicker ring mockups, which often resulted in severe surface oxidation and surface roughness. Hardness and peel test results, however, showed no indications of bulk metal contamination and joint embrittlement. Modified electrode designs and bonding techniques have been recommended to reduce the severity of surface heating and thus excessive surface oxidation and roughness.

The pulsed-current gas-tungsten-arc welding program was at a relatively low level of activity during 1984 due to equipment problems and other work priorities. The development of optimum welding procedures for the closure of titanium pipe mockups is underway.

ii) Copper: The test results of electron beam welding (EBW) of oxygen-free (OF) copper plates and electrolytic tough-pitch (ETP) copper pipe mockups have been reported. It was demonstrated that sound simulated copper lid welds could be made in a copper pipe mockup using selected EBW parameters. All these welds were free of any gross internal defects. Suitable combinations of beam power and welding speed must, however, be used to ensure a smooth weld surface which is free from surface defects such as erratic metal overflow, undercut and blow holes. Ultrasonic inspectability of the simulated lid welds has also been studied. Gas-metal-arc welding studies of 25 mm thick OF and ETP copper are in progress. Welding currents of 500 to 800 A and preheating temperatures of 200 to 400°C have been used.

iii) Inconel 625: A great deal of difficulty has been encountered in resistance/diffusion bonding trials on Inconel flat strips. During the bonding process, an oxide layer formed at a very fast rate, which appeared to impede the flow of current. At the lower heat inputs, no bond was formed.

When the heat input was raised to a sufficiently high level to overcome the oxide layer effect, the resultant heat generation at the interface was too high and caused the formation of a poor interface with a locally melted fusion zone. It is unlikely that further testing of resistance/diffusion bonding for Inconel will be undertaken.

3.2 Pulsed-Current-Gas-Metal-Arc-Welding

At the end of 1983 sufficient preliminary testing of the pulsed GMAW process had been undertaken to embark on procedure development through 1984 for a number of specific applications. These included temper-bead repair welding, stainless steel plate and piping fabrication for construction, all-position carbon steel pipe welding, and the application of stainless steel overlay. Support for this work was widespread throughout Ontario Hydro, with funding provided for the various investigations by Bruce Heavy Water Plant, Central Nuclear Services (CNS), Darlington Construction and Hydraulic Plant Equipment. All pulsed GMAW procedure development work was performed using an Osaka Transformer Corporation (OTC) Transistarc 350 power source. Other pulsed GMAW equipment was evaluated throughout the year (eg Airco Pulse Arc 350, Powcon 300SM) but none matched the controlled spray transfer provided by the OTC unit.

1) Temper-Bead Repair Welding: Using the 1983 pulsed-GMAW work and already established shielded-metal arc temper-bead procedures as a foundation, development work was carried out on a manual pulsed-GMA temper-bead welding procedure for heavy water plant applications. Using a 230°C preheat, the heat-affected zone (HAZ) of A516-Gr 70 base material could be tempered by a two-layer refinement technique. Optimum heat input ratios were determined for horizontal and vertical down welding positions using welding current and travel speed as variables. To accurately control heat input in manual welding procedures it is necessary to insist on a stringer bead welding technique, however, and the low heat input of pulsed-GMAW combined with the stringer bead technique can lead to lack-of-fusion defects in multilayer welds. Preliminary trials using weaving suggest that suitable grain refinement is possible with this technique, but accurate heat input control would be difficult to achieve. A mechanized weaving procedure is a possibility which should be pursued.

11) Stainless Steel Fabrication for Plate and Piping: Welding trials using type 304L stainless steel plate and piping material were conducted using pulsed-GMAW with a 1.2 mm diameter E308L consumable. Procedure development for the Darlington fuel bay liner and for the welding of piping in the 1G position (ie pipe rotated) was undertaken in conjunction with Darlington field personnel. The pulsed-GMAW process appears quite suitable for both applications, although some thought should be given to modifying the fuel bay liner joint geometry for future procedures. As a result of this work, a number of OTC pulsed-GMA welding power supplies have been ordered by Darlington field personnel for use in various construction applications.

iii) Carbon Steel All-Position Pipe Welding: A similar program was conducted in the area of all-position pulsed GMAW for carbon steel piping on behalf of CNS with the help of Pickering GS welding personnel. The program was designed to determine whether an acceptable root pass could be deposited using pulsed GMAW and to examine the quality of the subsequent fill and capping passes. Root welds were difficult although possible to make in vertical and horizontal plate. However, insufficient tolerance in the root welding procedure resulted in abandoning the root pass development for pipe. Pipes with GTAW root passes were filled and capped with pulsed GMAW in both the 2G and 5G positions. Mechanical testing of the welds was underway at year's end and preliminary results look positive.

iv) Overlaying of Hydraulic Turbine Throat Rings: A program was completed investigating the viability of pulsed-GMAW for applying stainless steel overlays to carbon steel hydraulic turbine throat rings. Pulsed-GMAW was found to be a viable process for out-of-position mechanized overlay welding of stainless steel with substantially greater productivity than manual shielded-metal-arc electrode welding. A smooth weld overlay of consistent thickness can be produced using a stringer bead technique and aiming the arc at the previous weld toe. Type 309L stainless steel should be used for the first overlay layer to balance Cr and Ni dilution, thus avoiding hot cracking. The Hydraulic Plant Equipment Department has purchased a transistorized pulsed GMAW power supply and is undertaking additional weld development work for future repairs.

3.3 Welding Automation and Robotics

The development of a computer-controlled remote arc welding capability has progressed over the past year in three areas:

- automated orbital pipe welding;
- robotic repair welding of heavy sections;
- data acquisition systems.

i) Automated Orbital Pipe Welding: The computer seam tracking program has been extensively modified to enable superior control of the orbital welding system during seam tracking of a weld path. Signal analysis is performed on a continuous sampling of the optical seam tracker's output, following each scan across the seam to determine the seam edges and, thus, the seam's location and gap width. In addition, the accuracy of the seam tracker focus can be determined, thereby allowing real-time focussing without interruption of seam tracking. The MINC computer now also has welding on/off control of the PW106 GTA power supply. Incorporation of a wire feeder onto the orbital weld head has allowed welding procedure development with the PW-106 power supply for demonstration of an automated weld on a 3" pipe mock-up. The procedures have required the generation of additional computer weld-control programs to allow for offset and oscillation during welding. An automated seam track and

subsequent multi-pass orbital weld have been demonstrated several times on the 3" pipe mock-up. However, although the orbital system has performed consistently, the seam tracking optical sensor has demonstrated itself to be insufficiently versatile for field application and will therefore be limited to use in only the present demonstration system.

After discussion with Generation Services Department, it was decided to progress in a new direction towards defining needs for automation, particularly with respect to the remote automated repair of nuclear piping of large (>8") diameter. A work program in this direction is now being pursued. Initially, a trip to Bruce GS was made to examine nuclear piping systems. Collection of information and evaluation of the capability of commercially available automated pipe welding systems (including available sensor and tracker systems) is in progress. The relative merits and potential of various welding processes for nuclear piping repairs, including pulsed-current GTA and GMA welding processes, are also under investigation. Based on the results of this investigation, recommendations will be made on the required capability and potential availability of an automated pipe welding system to satisfy OH's future nuclear pipe repair needs.

For several years, Ontario Hydro has supported a weld geometry prediction program (Arc Welding Computer Simulator, "ARCS") at the Welding Institute of Canada. The final phase of this program (ARCS IIb) was completed in 1984. Based on the findings of this program, a general information base of empirical and analytical relationships, which may be used to predict weld bead geometry for automated welding, has been established. As an extension of this program, a specific project, financed by Ontario Hydro, has been initiated in which AECL, Sheridan Park will provide research in the area of weld geometry prediction for automated GTAW root welds for piping applications. The program will identify key variables which must be considered for automated procedure development and for making optimum use of information generated during seam tracking. The output of the program will lead to a quantitative understanding of the relationship between weld joint geometry (fit-up), welding parameters and desired weld deposit geometry, and will provide direction regarding the research required to develop fully automated pipe welding.

ii) Robotic Repair Welding of Heavy Sections: In heavy section welding, the ability to surface track, map, and weld in an appropriate sequence to fill a cavity has been demonstrated. A Tektran power supply was used for GMA welding in the flat position. An ESPEL pulsed-GMA regulator was also used to develop an out-of-position welding capability, but this unit appears to be incompatible with the current/voltage regulation of the Tektran.

A data interpolation program was subsequently added to the heavy section software. A cavity can now be surface-tracked faster with the acquisition of fewer data points. Interpolation of data points that define a surface topography can then be performed to increase the data density. The interpolation enables cross sections of the surface to be taken between sampled data points, allowing substantially more freedom in weld path

selection. In addition, iso-altitude plots of a surface can be made at a greater density of data points for much improved user interpretation.

Solid state camera equipment has been purchased and has been demonstrated to be able to directly view a welding arc without damage to the camera, and also enable viewing for remote set-up and monitoring of the heavy section and orbital systems.

A 68000-based VME/10 microcomputer system was evaluated, and deemed to appropriately meet the needs of the automation program in a cost-effective manner. The VME/10 was purchased, along with a C compiler. The VME/10 is a powerful system that can support the more complex hardware and software development needs of the automation program and maintain software portability between other computer development systems that may be used in the future. The VME/10 will support all work stages from initial hardware and software development through to a custom, portable and modular end-user system. Also, the multi-user and multi-tasking ability of the system will allow the use of advanced software and control techniques.

Several meetings were held with welding and robotics personnel from Hydro Quebec (IREQ) to discuss details pertaining to a cooperative research program between OHRD and IREQ. The program is to develop a remotely-controlled automated system for the in-situ repair of cavitation damage in hydraulic turbine runners. This will combine our heavy section automated surface tracking and welding capability with the robotic arc gouging developed at IREQ. A visit to Saunders GS was made to observe the actual requirements and limitations pertaining to the repair of hydraulic turbine runners. The full size of the runners and the very limited access to the repair site were of particular interest.

A joint IREQ/OHRD proposal was prepared and submitted in June to the Generation Committee of the Canadian Electrical Association for funding to develop the proposed robotic system. The complete project involves the development and demonstration of a compact robotic system for performing the arc gouging, welding, and grinding to profile required in the repair of cavitation damage in hydraulic turbine runners. The total cost of the two-year project is estimated to be approximately \$400,000, with \$250,000 being requested from the CEA. Following a presentation given to the CEA at their November meeting, the proposal was accepted, and project work will commence in February, 1985.

iii) Data Acquisition Systems: A program has been initiated to study and develop a compact data acquisition system for instrument tube welding. The program involves replacing a strip chart recorder with an automatic data logger for monitoring current, voltage and welding speed. A system with faster response is required for new gas-tungsten-arc welding procedures being studied and developed. Moreover, there is considerable incentive to reduce the degree of subjectivity in chart interpretation inherent in the current practice. A preliminary detailed general specification has been prepared and

the system hardware components have been ordered.

The Apple II Plus computer has been linked to a Tektronix high speed digital oscilloscope for the data acquisition and logging required for instrumented Charpy signal processing. In addition, a menu driven system has been developed to enable data acquisition, logging of data on disk, and subsequent plotting of data. Programs that analyze and interpret the data can be developed and added to the system as may be required for specific tasks in the future. Of particular interest are the acquisition, logging, and interpretation of data from instrument tube welding, pulsed gas-metal-arc welding, and weld thermal cycle studies. The Apple II Plus computer has been enhanced with hardware and software, including the addition of a C compiler. This will allow software development compatible with the MINC and VME/10, also programmed in C.

3.4 Heavy Section Repair Welding Technology

i) Structural Integrity: The repair weld integrity program was initiated with CNS support in 1982, with the intent of addressing concerns regarding the structural integrity of non-post-weld heat-treated weld repairs. In collaboration with the Fracture Mechanics Unit and the Applied Structural and Solid Mechanics Section of Research Division, three areas of investigation have been pursued, including selection of a suitable approach to integrity assessment and experimentation to determine residual stress distributions and fracture toughness data applicable in such an assessment of a repair weld area. Early in 1984, a report was issued summarizing our conclusions regarding the use of the CEGB R6 integrity assessment method and the results of residual stress measurements on a simulated temper-bead weld coupon. The work on materials properties was also completed, with heat-affected-zone fracture toughness behaviour being characterized by the single specimen R curve technique using three-point bend specimens; test results showed the HAZ to exhibit fracture toughness equivalent to or greater than that of the base metal. The final phase of the program, to incorporate experimental data into a test case evaluating vessel integrity for a non-PWHT temper-bead weld repair using the R6 approach, will be completed in the first half of 1985.

ii) Heavy Water-Plant Temper-Bead Repair: Following the extensive temper-bead weld repair performed on the E4, 3rd stage hot tower at BHWP in 1983, considerable interest remains regarding the integrity of non-PWHT welds in wet H₂S service. The AMCA International review, commissioned by the AECB to address this issue, was completed in 1984. The final report viewed the Ontario Hydro temper-bead technique in a very positive light with only minor procedural changes suggested. The establishment of a definitive corrosion test program, agreeable to both Ontario Hydro and the AECB, was also recommended consistent with our own previously expressed view. Towards the end of the year, the temper-bead exposure samples which had been placed in the A plant enriching unit in 1981 were received for evaluation. Also at year's end, ultrasonic inspection of temper-bead repairs performed in process drain tank D-303 in 1981/82 suggested blister crack growth under the weld deposit.

It is hoped that samples can be obtained from the drain tank repair area for full metallurgical study early in 1985.

Further problems at the BHWP were the reason for additional heavy section repair procedure development. Sulphide stress corrosion cracking at sensitized weld regions in heat exchangers at BHWP 'A', prompted the evaluation of several potential repair techniques to repair these vessels (carbon steel clad with 321 stainless). A single layer stainless steel consumable repair was demonstrated to be successful for superficial defects. Subsequent work using a two-layer technique with 2.4 and 3.2 mm stainless steel electrodes also produced satisfactory results with weld HAZ hardness well below the maximum allowable of 250 VHN with both 100 and 177°C preheats. The inherent difficulty of welding stringer beads out-of-position with stainless steel SMAW consumables appears to be the major drawback with this repair technique.

3.5 Other Research Activities

i) Welding Health Studies: Volume II of the final report of the CEA-sponsored program on welding fumes was submitted to the CEA in December and is scheduled for distribution in January. The report describes the results of experimental work concerning the fume characteristics of SMA electrodes, welder fume exposure simulation testing, and evaluation of portable fume extraction equipment. The report provides an update on ongoing activities related to welding and health both nationally and internationally, and also outlines current Canadian priorities, specifically regarding fume hazard information dissemination, development of relevant guidelines and standards and the maintenance of an appropriate level of Canadian activity and expertise.

ii) Steel Weldability Studies: Welding Unit personnel continued to monitor, on behalf of the Canadian Electrical Association, a project to evaluate the weldability of alternative steels to A516 Gr 70 for pressure vessel fabrication. The project was scheduled for completion in 1984, but Chinook Fuel Innovations of Calgary who had been awarded the contract, went bankrupt early in the year. The project was subsequently transferred to Dr. B. Patchett at the University of Alberta for completion in April 1985. Recent work has demonstrated the capability of a small scale restraint test to evaluate hydrogen cracking susceptibility even at the hydrogen levels provided by low hydrogen (ie E7018) electrodes. Several alternate steels have been tested, including microalloyed low carbon steel, but none has yet been found with hydrogen cracking resistance markedly superior to the commonly used A516 alloy. Work is continuing to establish required preheat levels.

iii) Miscellaneous: In other CEA related activity, Welding Unit staff continued to act as corresponding monitors on ongoing research programs at BC Hydro (Metallic Overlay Materials for the Optimum Cavitation Performance of Hydraulic Turbines), the University of British Columbia (Hardfacing in Coal-Fired Power Stations, final report issued in 1984), and BC Hydro/AMCA

International (Optimization of Welding Procedures for Hydraulic Turbines). Comments were also provided as requested by the CEA regarding a number of other possible projects.

Welding Unit personnel were involved in the organization of two technical Working Group meetings held in May, under the auspices of the Canadian Council of the International Institute of Welding. The intent of these meetings was to provide a forum for Canada-wide information dissemination and possible collaboration in areas of welding research. A formal Working Group meeting, entitled "Microstructure/Fracture Toughness Relationships in HAZ and Weld Metal" was held at the Welding Institute of Canada with more than 30 attendees from Ontario, Quebec and Alberta. A more informal meeting was held the next day at OHRD, with eleven attendees from various research and manufacturing backgrounds, to discuss pulsed-current GMAW development. Both meetings were very well received by those attending, and two further meetings, in the areas of Fracture Mechanics/Fatigue and Welding Processes/Automation, are planned for May 1985.

3.6 Evaluation Of Welding Procedures and Materials

The metallurgical and mechanical property testing required for the qualification of welding procedures for use in Ontario Hydro, and for the evaluation of weldment quality in components supplied to Ontario Hydro by large fabricators, remained as a major activity of the Welding Unit during the year. Most of the nuclear quality evaluation work in 1984 still centred around Darlington GS, principally in the evaluation of tube-to-tubesheet welding, tubesheet overlays, tube bends, instrument tube tee welding, tube-to-tubesheet expansion and spent fuel bay liner welding. There was considerable miscellaneous work from the other nuclear stations, most notably the evaluation of test coupons being generated in developing mechanized welding procedures for bellows repair at Pickering GS 'A' and EFA ring welding for Bruce West Shift, qualification of stainless steel and Inconel overlay blocks for use in replacement moderator heat exchangers at Pickering GS 'B' and evaluation of thermite welds for Bruce GS 'B' fuelling machine rail.

Over and above the normally routine mechanical testing and metallographic evaluation associated with this work, major engineering input was provided in at least two problems areas. After repeated rejection of tube-to-tubesheet sample blocks for the Darlington GS moderator purification heat exchanger, recommendations were made to Muirhead Engineering to fit their weldhead with an extended copper heat sink to go inside the tube, thereby eliminating tube wall burnthrough and preventing weld metal cracking due to excessive base plate melting. Instrument tube tee joint samples submitted by Wescon Inc also failed repeatedly, prompting a brief in-house investigation. After sound welds were made with consistency, a visit to Wescon confirmed the problem to be equipment (weldhead) related. Once corrective action had been taken, sound tube tee welds could be produced.

Although the number of Ontario Hydro welding procedures qualified during the

year (6 nuclear and 2 structural) was somewhat lower than in previous years, the work involved in shepherding these procedures through the system up to MCCR approval was substantial. Several of the nuclear procedures were designed to cover as wide a range of thicknesses and material groups as possible in an attempt to reduce the total number of procedures in the welding manual. Considerable engineering input was provided with regard to Code interpretation, particularly with respect to impact property testing, and to satisfy MCCR concerns. In addition, the Unit played its usual role in reviewing and commenting upon new and revised welding procedures prior to issue. Welder performance testing and consumable certification were also carried out, including evaluation of ER70-S3 and E70-T4 electrodes. Based on the test results, suppliers were recommended for each type of electrode and put on the QPL.

3.7 Other Service Activities

Consistent with the Welding Unit's objective of a work program balance adjusted towards an increasing research fraction, small jobs and consultation work in 1984 was at a level somewhat below that of previous years. This may have been partially attributable to an emerging capability within Central Nuclear Services Department to deal with welding-related problems in nuclear plant operations on a day-to-day basis. Moreover, the Metallurgical Services Unit of Metallurgy Section has proven itself more than capable of addressing welding-related failures, and Materials Integrity Project personnel were called upon to address most thermal plant weldment problems.

Extensive circumferential cracking in the HAZ of a Stellite weld deposit in a Cr-Mo-V emergency stop valve by-pass plug from Lambton GS, could be attributed to a reheat cracking mechanism followed by thermal fatigue-induced crack propagation; a repair welding procedure was devised incorporating an Inconel 82 butter layer deposited at low heat input followed by completion of the weld with Stellite 6, resulting in a crack-free weldment after welding and post-weld heat treatment. Also submitted by Central Thermal Services for evaluation was an electron beam welded 410 stainless steel vane tenon; excessive weld metal hardness and a line of root cavities at the centre of the tenon has prompted the initiation of a program at OHRD to develop an alternative manual welding procedure. In collaboration with Metallurgical Services Unit, the feasibility of applying a protective weld overlay lining to the BHWP-D purge and absorber towers has been assessed; potential corrosion problems such as hydrogen blistering and disbonding were identified and analyzed quantitatively, and the submerged arc welding process has been suggested as the best method for overlay application. A report was also prepared for the BHWP addressing the potential for carbon steel vessel deformation due to creep during post-weld heat treatment; it was confirmed from available data that deformation in excess of allowable limits could occur during PWHT under certain loading conditions. Finally, Welding Unit personnel were periodically called upon to perform certain highly specialized welding and brazing jobs during the year; in particular, several days' work was again involved in welding end caps to sections of zirconium alloy pressure tube to

produce test vessels for the Materials Integrity Project's study on biaxial deformation of pressure tube and for the TRAC program on blister growth.

Welding Unit personnel continued to be involved in the activities of various committees and panels, including several Technical Advisory Groups reporting to the Standing Welding Panel (see Appendix C). The most active of these Groups during the year was the TAG on Health and Safety, with several meetings being held aimed at the establishment of priority issues, and the development of appropriate mechanisms for information dissemination to field welding personnel. In external committee work, the Advisory Committee on Welding reporting to the Director of the Industrial Materials Research Institute (National Research Council of Canada) completed its assessment of IMRI's welding research activities. The Committee's final report has been prepared, with specific recommendations regarding the difficult relationship between IMRI and the Welding Institute of Canada.

3.8 Reports, Presentations and Publications

The Welding Unit generated a total of 40 Research Division reports in 1984, as listed in Appendix A. This was substantially below the levels of previous years, again reflecting the reduced service work activity during the year, with the transfer of responsibility to Metallurgical Services. At the same time, an effort was made to streamline the reporting system on occasion, for example by incorporating the results of repeat submissions for a given qualification into a single report. External publications and presentations prepared by Unit staff in 1984 are given in Appendix B.

4.0 1985 WORK PROGRAMS

During 1985, the Welding Unit will continue to pursue the work program areas listed in Section 1.0. Although objectives have been set for these programs in 1985, as summarized below, unanticipated demands from field support and service work requirements may be expected to have a substantial effect on the Unit's ability to achieve these objectives. With the relatively high level of transfer and externally (CEA) funded research and development-type work load committed for 1985 and beyond, however, it may be justifiable to consider a staff increase, either temporary or regular to offset the impact of additional work demands.

4.1 Nuclear Fuel Waste Disposal Container Welding

The emphasis of the 1985 work package will be on carrying out demonstration welds on ring sections and pipe mockups using various welding processes under study in 1984.

Electron beam welding studies will be concentrated on oxygen-free copper pipe mockups. Specific areas of concern, including weld joint fit-up, weld overlaps, out-gassing from spent fuel bundles, and thermal cycles at the inner

wall of a copper container resulting from electron beam welding will be investigated.

Gas-metal-arc-welding studies will also be carried out on thick copper plates and pipe mockups. The welding current and preheat temperature will be selected based on the weld quality and the high temperature excursion at the inner container wall resulting from welding and preheat cycles.

Resistance/diffusion bonding studies will be extended to include grade 12 titanium ring sections. Edge-bonding techniques will be investigated to provide crevice-free joints.

In collaboration with the welding automation program, the requirements of a remote arc welding system for the final closure welding of spent fuel containers will be defined, particularly concerning gas-tungsten arc welding of thin-walled titanium containers and gas-metal-arc welding of thick-walled copper containers. Areas to be investigated include computer-controlled seam tracking, closed-loop feedback control of welding parameters, definition of required tolerance levels and repeatability, and remote-controlled repair welding requirements, ie inspection, grinding, gouging, cutting and rewelding.

4.2 Pulsed Current Gas-Metal-Arc Welding

During 1984, pulsed-GMAW was applied to a number of specific applications, with varying results. In general, the viability of the process was successfully demonstrated to the point that several pulsed-GMAW power supplies have been ordered for field application. Certain difficulties and questions remain, however, which require resolution in 1985.

Development work will continue in the area of temper-bead procedure development with pulsed-GMAW. To counteract the previously observed formation of lack-of-fusion defects, procedures will be attempted which include either manual or mechanized weaving. Weaving will effectively increase heat input to improve weld penetration, but must be carefully controlled to guarantee the consistent heat input ratio required for the temper-bead technique and to maintain an all-position welding capability.

More fundamental work will be undertaken to evaluate the effects of shielding gas and welding wire composition, on both weld bead geometry and weld metal mechanical properties. The purchase of a more sophisticated welding power supply is also planned which will allow us to assess the influence of current pulse shape characteristics (ie peak height, pulse width, background current level) on weld quality and integrity.

An important area for development in pulsed-GMAW in 1985 is related to the CEA contract on robotic turbine runner repair. The feasibility of producing sound horizontal-position stainless steel weld deposits with a mechanized system has already been demonstrated for the hydraulic throat ring repair. This capability will have to be extended to all positions, and must be adapted to a

more versatile, automated (robotic) system. Moreover, it will likely be necessary to develop welding procedures for depositing cobalt-based alloys such as Stellite 21.

4.3 Welding Automation and Robotics

1) Robotic Repair of Hydraulic Turbine Runner Cavitation: This two-year, \$400,000 OHRD/IREQ joint project, being funded in part by the CEA, will commence in February 1985. The project's objective is the development and demonstration of a compact robotic system for performing the arc gouging, welding, and grinding/milling required for the in-situ repair of cavitation damage in hydraulic turbine runners. Work program details will be given in a report to be issued early in 1985, along with summaries of the robotized gouging work done at IREQ and automated welding development at OHRD. Work program areas for the first year of the project include:

- 1) evaluation of commercially available robotic systems;
- 2) decision to make or buy robotic system;
- 3) manufacture or purchase of robot and control systems;
- 4) initial application of the robotic system to surface tracking and welding.

In parallel to the above, work will continue in pulsed-GMA welding at OHRD and in arc gouging at IREQ specific to automation needs, and investigations will commence in the area of grinding/milling technology. An important requirement during the year will be the development of appropriate hardware and software to interface the powerful VME/10 computer to the robotic system.

1i) Automated Orbital Pipe Welding: The investigation into automated repair welding of nuclear piping will be expanded in 1985, with continuing support from Generation Services Department and additional funding expected from CNS. The proposed work program for 1985 includes the following:

- 1) Review Hydro's nuclear piping systems, typical piping tolerances and existing repair welding procedures to assess automation needs.
- 2) Collect information and evaluate the capability of commercially available automated pipe welding systems, including seam trackers and sensors, in terms of their ability to satisfy perceived automation needs.
- 3) Monitor the contract with AECL on weld geometry prediction.
- 4) Based on the above, define and implement a suitable approach towards development of an automated pipe welding capability

for nuclear piping.

In addition, further work may be done to improve the existing in-house orbital welding system, including modification of the PW106 power supply, incorporation of added control with the VME/10 and a modified interface, and addition of a better seam tracking sensor.

iii) Data Acquisition System Development: Work will continue on the program to study and develop a compact computer-based data acquisition system for instrument tube welding, to replace the presently used strip chart recorder for monitoring current, voltage and welding speed. The system hardware components should be received early in 1985 after which time the software development can begin.

Work will also continue on the Apple/oscilloscope data acquisition system. An operating manual will be written for the system to ease the job of software development for interpretation and analysis of acquired data. Of particular interest is the data from instrument tube welding that will eventually be acquired by the above-mentioned custom-built data acquisition system. Also of interest is the data from pulsed gas-metal-arc welding and weld thermal cycle studies.

4.4 Repair Welding Technology

i) Structural Integrity: The final phase of the repair weld integrity program, to incorporate experimental data into a test case evaluating vessel integrity for a non-PWHT temper-bead weld repair, can now be undertaken. Heat-affected-zone fracture toughness data has been generated and appropriate assumptions can be made regarding a viable residual stress distribution around the repair area, for incorporation into the CEGB R6 assessment model. A final report is expected in the first half of the new year.

ii) HAZ Thermal History: As an alternative to determining HAZ fracture toughness properties for integrity assessment from relatively large-scale and costly simulated repair weld coupons, it may be possible to utilize small-scale fracture toughness testing coupons which have been subjected by simulation to the thermal cycling to which the HAZ is exposed during welding. A co-funded project proposal has been submitted to the CANDEV-Mechanical Process Equipment Program, to investigate whether it is feasible to utilize thermally simulated HAZ specimens for fracture toughness investigations and/or welding repair procedure development, particularly for steels other than A516-Gr 70. During 1985, base line fracture toughness (J_{IC}) data will be generated for A516-Gr 70 repair weld HAZs, and thermal cycle simulation studies will be initiated to reproduce the metallurgical effects of real-weld thermal cycle history with a Gleeble thermal simulator.

iii) Heavy Water Plant Repairs: The focus at the BHWP on temper-bead weld repair service performance will remain, with the evaluation of the long-term exposure samples from 'A' plant and possible metallurgical evaluation of the

process drain tank repair. As previously noted, work will continue towards the development of pulsed-GMA temper-bead welding procedures, with the specific application of HWP tower corrosion repair in mind. The eventual development of a robotic system for this type of work has also been proposed. Action might be expected in initiating a definitive temper-bead corrosion test program in collaboration with the AECB. It is also likely that further work will be necessary in the development and laboratory evaluation of appropriate repair procedures for the cracked clad heat exchangers at BHWP 'A'.

4.5 Service Activities

Although a good deal of the work load associated with external fabricator product quality evaluation will be absorbed by the Metallurgical Services Unit in 1985, a considerable amount of service work will remain requiring Welding Unit attention. As noted in Section 3.6, problems often arise regarding fabricator weld quality which may benefit from the expertise and laboratory facilities residing in the Unit. At the same time, welding procedure development and qualification work will continue at or above the 1984 level as construction continues at full speed at Darlington GS; moreover, a considerable amount of such work has already been scheduled in support of LSFCR at Pickering GS 'A'. The periodic re-assessment of E7018 electrodes for inclusion on the Qualified Products List (QPL) is overdue, and may be requested in 1985. Work can also be expected related to the needs of the operating stations and for general consulting and assistance with weld-related failure investigations. Finally, work will continue in the monitoring of various CEA contracts and in conjunction with the activities of several committees, both internal and external.

5.0 CONCLUDING REMARKS

During 1984, the staff of the Welding Unit continued to work towards the Unit's objectives of pursuing welding-related research of both short and long term benefit to Ontario Hydro, while at the same time providing the Corporation's welding community with timely and effective laboratory services and engineering expertise. A fundamental change was observed in the Unit's work mix during the year, however. With the development of relatively broad-based support for our research programs, in the form of increased transfer and external funding, it has become both necessary and desirable to aim for a reduced service work load. Unfortunately, the relatively unpredictable nature of this type of work makes it difficult to ensure that delays will not occur in the achievement of research program objectives. Even in 1984, almost \$50,000 in committed transfer funds could not be spent by year's end because of urgent field requests, with resultant delays in several of the longer term work programs.

A more subtle problem which must be addressed is the erosion of the Welding Unit's capability to address longer term Corporate welding needs and opportunities. In previous years, research work areas such as temper-bead welding, pulsed-GMAW and welding automation were initiated by the Welding Unit

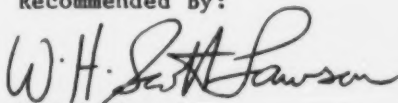
primarily with Research Division funding. The value to the Corporation of output from these work areas can be measured by their adoption in plant maintenance and construction, and by the amount of transfer funding now being provided to continue with this work. It is not unrealistic to suggest that many other areas exist for fundamental studies to be initiated, for example in welding metallurgy or welding process and equipment development, which could be of great benefit to the Corporation some years down the road.

Unfortunately, the committed work program for the Unit is now fully established, and already heavily taxes the Unit's limited staff resources. The potential for effectively pursuing a realistic level of exploratory research in some new area of promise is minimal. Some relief might be gained by relying on external research organizations; membership in the British Welding Institute should merit serious consideration in 1985, particularly now that it is affiliated with the Edison Welding Institute (Battelle Institute/Ohio State University) in Ohio. But substantial discretionary time is also required to gain full benefit from this potentially valuable resource. Therefore, on the basis of a proven record in providing Ontario Hydro with research work of practical benefit, and a need to maintain a forward-looking outlook for continuing progress in welding, serious consideration should be given to adding to the Welding Unit's staff complement in 1985.

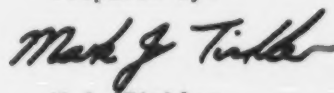
ACKNOWLEDGEMENTS

The author would like to thank the members of the Welding Unit both for their contributions to this report and for their continued dedication to the Unit's work program throughout the year. The continuing cooperation and assistance of Metallurgical Services staff is also appreciated.

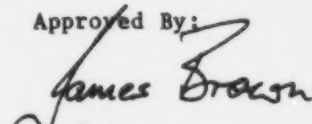
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APPENDIX A

REPORTS ISSUED IN 1984

- 84-57-K Technical Assistance to AECL - Electron Beam Welding of Thick-Walled Copper Containers for Nuclear Fuel Waste Disposal, Phase II (P.Y.Y. Maak)
- 84-58-K Titanium Resistance/Diffusion Bonding Studies, Phase II (P.Y.Y. Maak)
- 84-285-K Procedure Development for Littlelong GS Weld Overlay Repair (J.W. Prince)
- 84-409-K Trip Report - Robots 8 Conference and Exposition (E.de Buda/S.C.McNabb)
- 84-421-K Repair Welding Development for BHWP Heat Exchanger Shells (J.W. Prince)
- 84-422-K Electron Beam Welding of Thick-Walled Copper Container for Nuclear Fuel Waste Disposal - Phase III (A) (P.Y.Y. Maak)
- 84-423-K Electron Beam Welding of Thick-Walled Copper Container for Nuclear Fuel Waste Disposal - Phase III (B) (P.Y.Y. Maak)
- M84-5-K Welding Unit - Review of 1983 Work Program and Proposed Work for 1984 (M.J. Tinkler)
- M84-9-H Evaluation of Flux Cored Welding Wires (P.Y.Y. Maak)
- M84-10-K Tube-to-Tubesheet Seal Weld Repair Qualification Sample, Coolers, Darlington GS (P.Y.Y. Maak)
- M84-18-K Feasibility of Weld Overlay Lining of BHWP-D Purge and Absorber Towers (M.A.Clark/J.W.Prince)
- M84-21-K Tube-to-Tubesheet Qualification Samples, Bleed Condensers, Darlington GS (P.Y.Y. Maak)
- M84-23-K Second Submission of Tube-to-Tubesheet Qualification Sample, Purification Moderator Heat Exchanger, Darlington GS (P.Y.Y. Maak)

M84-25-H Tube-to-Tubesheet Expansion Qualification Shutdown Coolers, Back-up Gland Supply Coolers, Bleed Coolers, Darlington GS (J.Prince/D.Galbraith)

M84-27-K Progress Report - Integrity of Non-Post Weld Heat-Treated Weld Repairs for Heavy Section Vessels (J.W. Prince)

M84-41-H Examination of Instrument Tube Tee Weld Joints, Second Submission, Darlington GS (J.Prince/J.Galloway)

M84-75-K Procedure and Qualification Tests, Stainless Steel Liners, Darlington GS (P.Y.Y. Maak)

M84-81-H Third and Fourth Submission of Tube-to-Tubesheet Qualification Sample, Purification Moderator Heat Exchanger, Darlington GS (P.Y.Y.Maak/D.Galbraith)

M84-86-K Examination of Instrument Tube Tee Weld Joints, Fourth Submission, Darlington GS (J.W. Prince)

M84-92-K Evaluation of Pulsed Gas Metal Arc Welding Equipment (R.W. Hopkins)

M84-99-K Chemical Analysis of Thermite Weld Risers, Bruce 'B' F/M Rail (P.Y.Y. Maak)

M84-100-K Operation and Evaluation of the PW-106 Welding Power Source (J.G. Galloway)

M84-110-K Development of Pulsed Gas Metal Arc Welding (P-GMAW) of Stainless Steel (R.W. Hopkins)

M84-113-K Overlay Qualification Sample Moderator Heat Exchanger Replacement Tube Bundle, Pickering GS "B" (J.W.Prince)

M84-118-K Creep of Carbon Steels during Post Weld Heat Treatment (J.W. Prince)

M84-119-K Examination of 19 mm Instrument Tube Tee Weld Joints, First Submission, Darlington GS (J.W. Prince)

M84-126-K Weld Overlay Disbonding Workshop, Ottawa, September 17, 1984 (J.W. Prince)

M84-127-K Evaluation of an Electron Beam Welded Vane Tenon (P.Y.Y. Maak)

M84-135-K Cracking and Welding Repairs on Lambton TGS ESV By-Pass Valve Plugs (J.G. Galloway)

M84-155-K Bridge Repair Weldability Evaluation (R.W.Hopkins)

M84-175-K Evaluation of Fusion Welds in a Prototype Thin-Walled
Irradiated Fuel Container (P.Y.Y. Maak)

SQ84-1-K Procedure and Filler Metal Qualification Tests, PA-671,
Pickering GS 'B' (P.Y.Y. Maak)

SQ84-2-K Procedure Qualification Test, PN-102-SM (P.Y.Y. Maak)

SQ84-3-K Procedure Qualification Test, SA-531, Aluminum
Structural Welding Procedure (J.W. Prince)

SQ84-4-K Procedure Qualification Tests, PN-232, Darlington GS
(P.Y.Y. Maak)

SQ84-5-K Procedure Qualification Test, PN-107, Darlington GS
(P.Y.Y. Maak)

SQ84-6-K Tube-to-Tubesheet Expansion Qualification Purification
Moderator Heat Exchanger, Darlington GS
(P.Maak/D.Galbraith)

SQ84-7-K Procedure Qualification Test, PN-229 (J.W. Prince)

SQ84-8-K Procedure Qualification Test, PN-102, Darlington GS
(J.W. Prince)

SQ84-9-K Procedure Qualification Tests, P-618, Darlington GS
(P.Y.Y. Maak)

APPENDIX B

EXTERNAL PRESENTATIONS AND PUBLICATIONS

M.J. Tinkler	"Repair of Heavy Section Components - Automated Welding Development", Welding Institute of Canada, Toronto Chapter (presentation - January 11, 1984).
M.J. Tinkler	"Stainless Steel Instrument Tube Welding Problems", Metallurgical Research Department Seminar (presentation - March 16, 1984).
M.J. Tinkler	"Variable Penetration Characteristics in Welding Stainless Steel", Welding Research Council High Alloys Committee Meeting, Pittsburg (presentation - May 17, 1984).
Y.J. Kim and J.W. Prince	"Temper-Bead Heat-Affected Zone Properties in A516-Gr 70 Steel", 1984 ASME Pressure Vessel and Piping Conference, San Antonio, Texas, June 18-22 (presentation by Y.J. Kim and publication in conference proceedings).
P.Y.Y. Maak	"The Effect of Air Contamination in the Argon Shielding Gas on the Mechanical Properties of Titanium Gas-Tungsten-Arc-Welds", AECL Technical Report No TR-282, July 1984.
P.Y.Y. Maak and R.T. Shui	"Titanium Resistance/Diffusion Bonding Studies - Phase One", AECL Technical Report No TR-254, August 1984.
P.Y.Y. Maak	"Electron Beam Welding for Copper Used Fuel Disposal Containers - Phase One", AECL Technical Report No TR-252, August 1984.
J.W. Prince	"Temper-Bead Welding Repair of A516-Gr 70 Steels", ASME Code Section XI Working Group Meeting on Repair Welding, New York City (presentation - November 15, 1984).
M.J. Tinkler, S.C. McNabb, J.L. Fihey (IREQ)	"Proposal for the Development of a Robotic System for Hydraulic Turbine Runner Repair", CEA Generation Committee Meeting (presentation by M.J. Tinkler - November 21, 1984).

- P.Y.Y. Maak "Electron Beam Welding of Thick-Walled Copper Containers for Nuclear Fuel Waste Disposal - Phase Two", AECL Technical Report No TR-253, December 1984.
- J.W. Prince "Consideration of Specific Applications for Mechanization of Gas-Metal-Arc-Welding, Welding Institute of Canada/Conestoga College Workshop - Productivity Through Mechanized and Automated Welding Processes, Guelph, Ontario (presentation - December 7, 1984).
- M.J. Tinkler "Evaluation and Control of Fumes Produced During Welding - Volume II : Experimental Evaluation", Canadian Electrical Association Report 000G156, December 1984.

APPENDIX C

COMMITTEE AND PANEL MEMBERSHIP

Standing Welding Panel	M.J. Tinkler
Advisory Groups-Welding Electrodes	P.Y.Y. Maak
Welding Equipment	R.W. Hopkins
Nuclear Repair Welding	J.W. Prince
Welding Manual	W.H.S. Lawson*
Welding Manual Revision	M.J. Tinkler
Health and Safety	M.J. Tinkler
Research Division Task Force on Robotics Initiatives	S.C. McNabb/ M.J. Tinkler
Industrial Materials Research Institute, NRC - Director's Advisory Committee On Welding	M.J. Tinkler
Canadian Council of International Institute of Welding - Task Force on Future Directions	M.J. Tinkler
Welding Institute of Canada - Research Board	W.H.S. Lawson
Welding Institute of Canada, Toronto Chapter - Education Chairman - Treasurer	P.Y.Y. Maak W.H.S. Lawson
Northern College AAT - Welding Advisory Committee	W.H.S. Lawson
Welding Research Council - High Alloys Committee & Subcommittee on Welding of Stainless Steels	M.J. Tinkler

*W.H.S. Lawson is Supervising Engineer -
Metallurgy Section